TRW

Advanced Space Communications Architecture Study

Volume 1 — Executive Summary

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Prepared for
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, OH 44135

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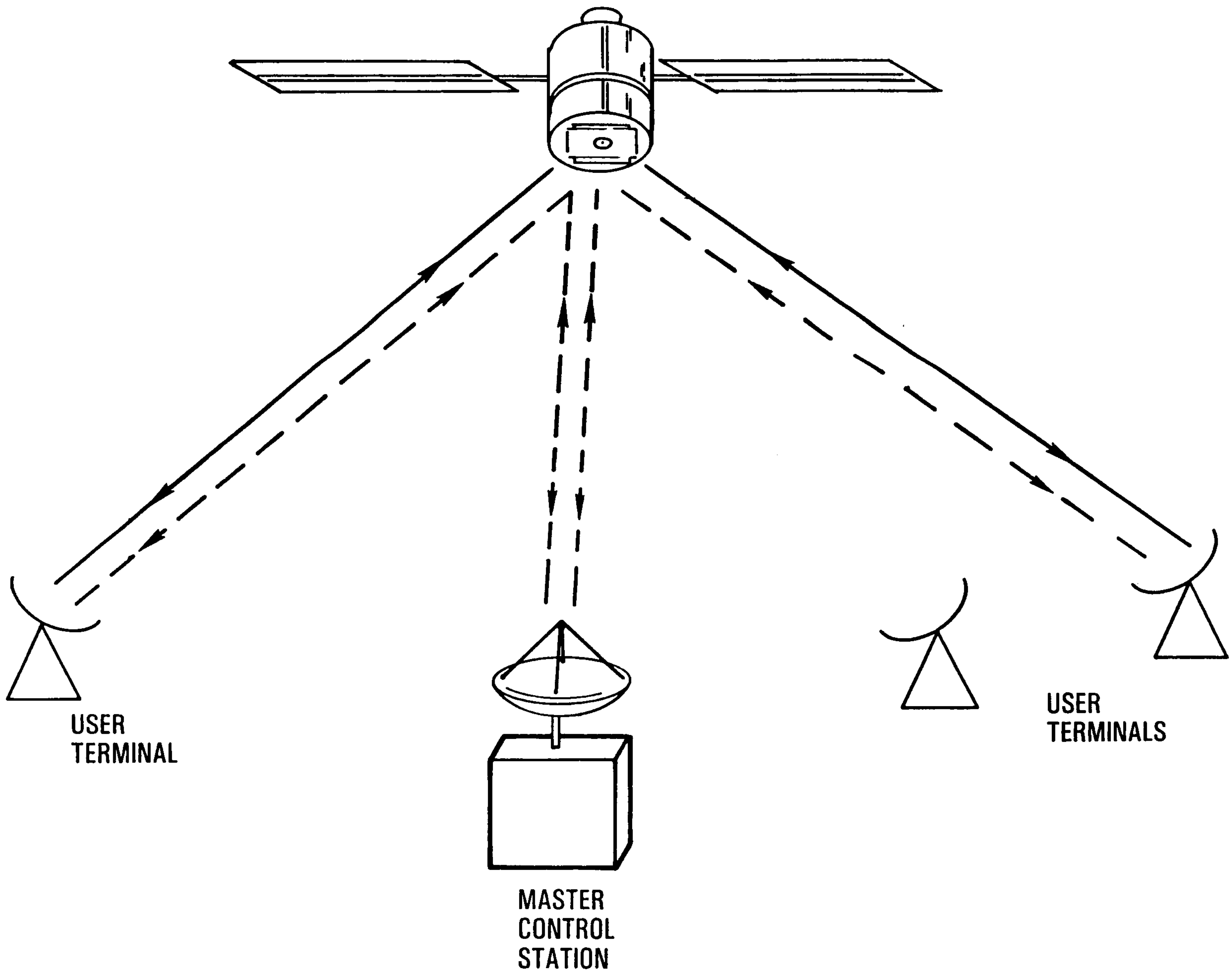
EXECUTIVE SUMMARY

Because of rapid advances in fiber optics communications, trunking traffic will for the most part be carried terrestrially in the future. As a result, point-to-point satellite communications will be dominated by thin-route applications. This report presents the results of a 12-month study to identify satellite system architectures that are most suitable for customer premise service (CPS) communications at 30/20 GHz (Ka-band). However, the system architectures examined are equally applicable to operation at 14/11 GHz (Ku-band).

The satellite links in the type of system under consideration are shown in Figure 1. Complete single-hop interconnectivity is provided between any pair of system users. To establish such a connection, a user requests either a one-way channel or a two-way circuit, as needed, from the master control station. These requests are transmitted over an orderwire channel, typically making use of a random access protocol. When the circuit is no longer needed, it is restored to the pool of circuits available for reassignment. A user is only charged for the period in which he is assigned a circuit, much the same as in the terrestrial telephone network.

Because the intent is to serve large numbers of users, emphasis is placed on system designs that permit low-cost user terminals. The terminal antenna diameter is limited to 1.2m in most of continental United States (CONUS); however, 1.8m antennas are permitted in heavy-rainfall

Figure 1. Satellite Links



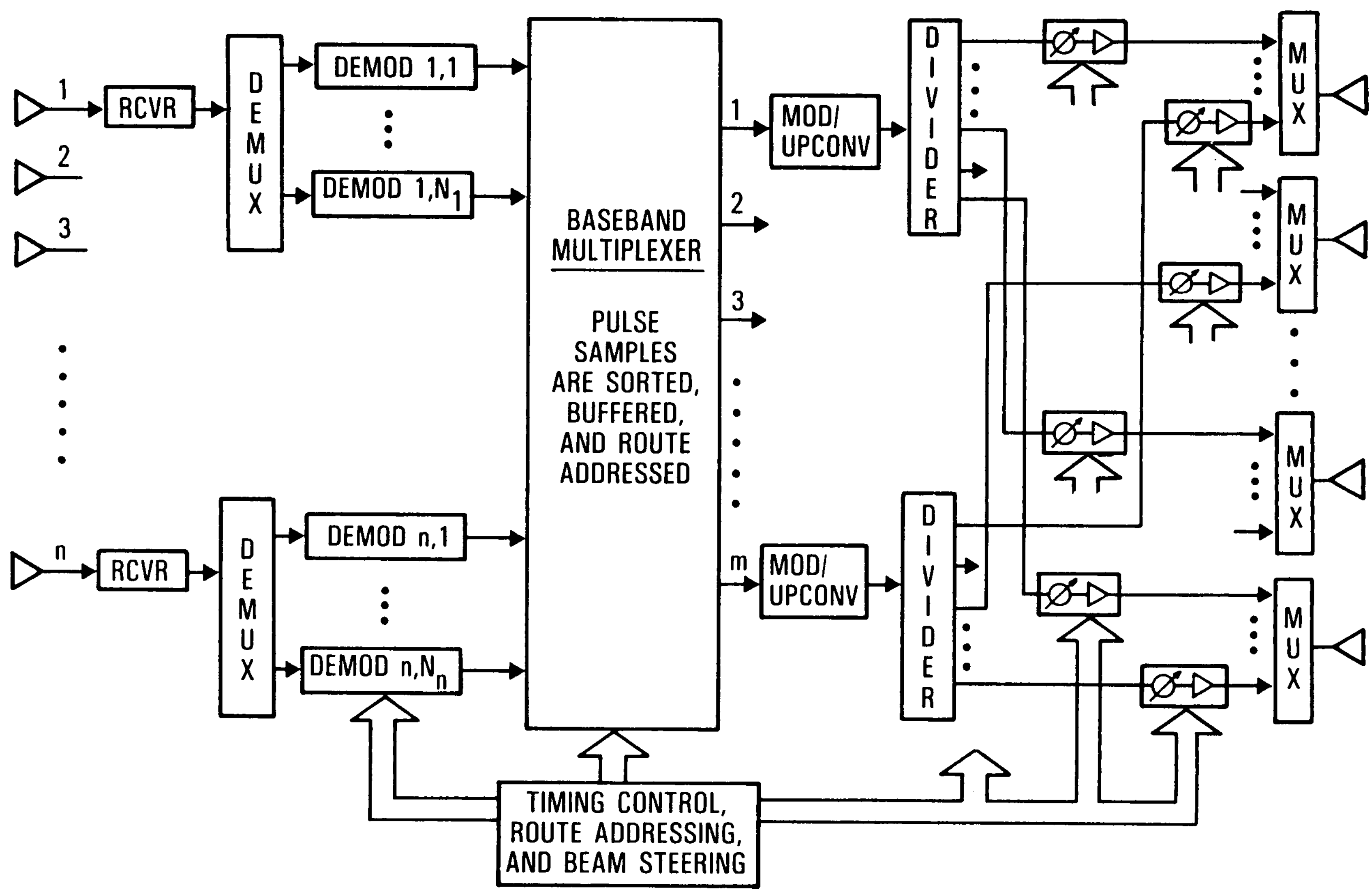
areas to maintain system availability. A frequency-division multiple access (FDMA) uplink signal format is selected to minimize terminal EIRP requirements. A 2W, solid-state transmitter suffices for a 64-kbps carrier, while providing a minimum end-to-end link availability of 0.99.

The general form of the satellite payload is shown in Figure 2. A multibeam satellite receive antenna provides CONUS coverage through a relatively small number of fixed area beams. The receiver output for each uplink beam is demultiplexed into distinct frequency segments, each of which contains a large number of uplink channels. Each frequency segment is fed to a "bulk" demodulator, which converts the composite FDMA input into a time-division-multiplexed (TDM) data stream in which the symbols of individual input channels are interleaved.

The baseband multiplexer transforms the large number of demodulator outputs into a small number of wideband data streams for downlink transmission. Each wideband data stream is transmitted via a separate scanning spot beam generated by a phased-array antenna configuration. Each scanning beam dwells on a given spot long enough to transmit a predetermined number of symbols from each uplink channel intended for a terminal within that spot.

The baseline set of system parameters was determined by an interrelated set of trades that focused on: user terminal cost, satellite transmit antenna power requirements and complexity, bulk demodulator power requirements, and efficient utilization of the Ka-band fixed-satellite frequency allocation.

Figure 2. Satellite Payload Functional Block Diagram



In the baseline system, a total of 11,250 user terminals can simultaneously access a single satellite, half using right-hand circular polarization (RHCP) and the other half using left-hand circular polarization (LHCP). Each of these transmissions is received by one of eight uplink satellite beams. There are 100 bulk demodulators, each of 10-MHz bandwidth and capable of demodulating 112 64-kbps uplink transmissions. The baseband multiplexer converts the demodulator outputs into four 180-Mbps data streams. Two of these data streams are transmitted on each of two senses of polarization. Two separate transmit antennas are used. Each antenna contains 331 radiating elements and transmits a pair of carriers of opposite polarization. A total of 60 overlapping downlink spots are required for CONUS coverage. Each downlink beam typically scans over 30 spots and dwells on each spot long enough for transmission of ten symbols from each uplink channel that is directed at a terminal within the spot.

Technology developments in three key areas are needed for implementation of the satellite system described. Digital bulk demodulators based on fast Fourier transform (FFT) techniques should become practical for satellite application in the next few years. Rapid advances in high-capacity memory chips will permit the multiplexing of uplink data streams onto downlink carriers through use of "memory-based" multiplexers. Finally, monolithic microwave integrated circuit (MMIC) technology is essential to cost-effective implementation of the satellite transmit antennas.

Each satellite of the baseline design is estimated to weigh 5600 lb

and consume 6850W of power during normal operation. (Provision is made for operation at one-fourth capacity during eclipse.) The payload accounts for 1000 lb and 5000W of the above totals. The nonrecurring cost for satellite development is $110 million. The first-unit cost is $113 million, with subsequent unit costs reduced according to a 90-percent learning curve. The cost to place each satellite in geosynchronous orbit is assumed to be $120 million.

In computing the charge imposed on system users, the system operator is assumed to own all space and ground assets. The satellite cost includes a manufacturer's profit of 12 percent. The user terminal cost is estimated at $25,000. In the assumed traffic profile, the peak demand is 5,000 64-kbps channels at the start of operations, growing at a 20-percent annual rate to nearly 31,000 channels after ten years of operations. Three operational satellites, together with an on-orbit spare, are needed to handle the final traffic volume. A fifth satellite, in the role of a ground spare, is procured in lieu of obtaining insurance against system failures.

The revenue per active channel required to realize each of three internal rates of return (IRR) is shown in Figure 3. In each year of operation, only those channels needed to meet the peak traffic demand are considered to be active. The IRR is computed for a 14-year program: four years for development and manufacture of the first satellite, followed by ten years of operations. The number of terminals installed on customer premises is an important parameter in determining the required revenue. The number of terminals must at least equal the peak channel demand. A

Figure 3. Required Revenue ($000 per Channel-Year)

Rate of Return (Percent)	Relative Number of Terminals		
	x1	x2	x3
20	37.1	46.5	55.8
25	44.9	56.6	67.4
30	55.8	68.1	80.3

larger number of terminals results if (1) any of the terminals engage in one-way communications, or (2) some of the terminals are idle during the period of peak channel demand. The required revenue is shown in Figure 3 for a terminal complement equal to one, two, or three times the minimum number.

The subscriber charge corresponding to the revenue per channel-year of Figure 3 is shown in Figure 4. The subscriber charge is derived from the assumption that each active channel is occupied for a total of 9000 minutes per month, which is equivalent to slightly more than seven hours per business day. The subscriber charge of $0.52 per channel-minute, which corresponds to an IRR of 25 percent and a number of terminals equal to twice the minimum value, will be taken as representative for comparison with similar terrestrial offerings.

At present, three long-distance carriers offer switched 56-kbps service. This service is currently limited to a two-mile radius surrounding the carrier's "point of presence" (POP) in a major city. (Extended range of service should become available with introduction of similar service by the regional Bell operating companies.) These terrestrial offerings have both a per-minute usage charge and a port charge. The total per-minute charge for a (duplex) 56-kbps circuit ranges from $0.46 to $1.52, depending on the carrier and the monthly usage. The satellite system charge of $0.52 per channel-minute must be doubled, so that it corresponds to a duplex 56-kbps circuit. The resulting charge of $1.04 per circuit-minute lies midway in the range for switched 56-kbps terrestrial service.

Figure 4. Subscriber Service Charge
(¢ per Channel-Minute)

► **Assumption: average channel usage = 9000 min/mo**

Rate of Return (Percent)	Relative Number of Terminals		
	x1	x2	x3
20	34.4	43.1	51.7
25	42.5	52.4	62.4
30	51.7	63.1	74.4

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16. Abstract
This study investigates the technical feasibility and economic viability of satellite system architectures that are suitable for customer premise service (CPS) communications. System evaluation is performed at 30/20 GHz (Ka-band); however, the system architectures examined are equally applicable to 14/11 GHz (Ku-band). Emphasis is placed on systems that permit low-cost user terminals. Frequency division multiple access (FDMA) is used on the uplink, with typically 10,000 simultaneous accesses per satellite, each of 64 kbps. Bulk demodulators onboard the satellite, in combination with a baseband multiplexer, convert the many narrowband uplink signals into a small number of wideband data streams for downlink transmission. Single-hop network interconnectivity is accomplished through use of downlink scanning beams.

Each satellite is estimated to weigh 5600 lb and consume 6850W of power; the corresponding payload totals are 1000 lb and 5000W. Nonrecurring satellite cost is estimated at $110 million, with the first-unit cost at $113 million. In large quantities, the user terminal cost estimate is $25,000.

For an assumed traffic profile, the required system revenue has been computed as a function of the internal rate of return (IRR) on invested capital. The equivalent user charge per-minute of 64-kbps channel service has also been determined.

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